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Radiochromic Film Measurement of Spatial Uniformity for a Laser Generated X-ray Environment

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Radiochromic Film Measurement of Spatial Uniformity for a Laser Generated X-ray Environment [a), b)]

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An existing X-ray Source Application test cassette was modified to hold multiple X-ray filter materials followed by two radiochromic film types (FWT-60 and HD-810 Gafchromic® film) to qualitatively characterize the spectral-spatial uniformity over the XRSA sample field of view. Multiple sets of film were examined and nominal set was determined. These initial, qualitative measurements suggest a low-energy regime (E < 3 keV) spatial anisotropy and spatial isotropy at higher energies (E> 3 keV).

I. INTRODUCTION

A. Overview

Intense, multi-keV X-ray sources are needed for imaging, radiography, and material study applications.[1-4] We use these and other X-ray sources for materials response studies that require a well-characterized source with respect to energy, time, and space. We report on a simple technique for estimating spatial non-uniformity developed during preparation for recent X-ray source development target shots at the OMEGA laser facility. Our test team was initially recommended to assume the source was spatially isotropic. Our lead analyst immediately called this into question but there was no available measured data and/or measurement technique to easily evaluate this assumption. The uniformity question was further called into question by anomalous material-response observations in a May 2008 OMEGA experiment and test series.[5]

B. Background

Our test team has been participating in a series of X-ray source characterization and materials response experiments since 2006. The experimental program was initiated to evaluate recent progress in carrying out X-ray radiation-effects tests using laser-generated X rays. These tests were done on the 30 kJ OMEGA laser at the Laboratory for Laser Energetics (LLE) at the University of Rochester, Rochester, NY. The first of these experiments occurred on 14 July 2006. The first experiment was conducted as a six-shot series noted as OMEGA II with the objective to characterize the X-ray source energy and temporal characteristics as well as gain experience with exposing materials for X-ray response modeling. The OMEGA II experiment met the test objectives and provided experience and excellent correlation with the pre-test modeling.

The next test series, OMEGA III, was executed on 8 May 2008. The success of OMEGA II produced excitement with this new X-ray materials response source and therefore many materials sample vendors provided samples to be evaluated during OMEGA III. A single-sample cassette was obviously inadequate to meet the demand for the OMEGA III test series. OMEGA III included ten X-ray shots fired during a 12-hour day using a laser driven Ge-doped aerogel[4] X-ray source. The number and variety of samples evaluated during the OMEGA III test series required a new multiple-sample test cassette to be developed. The larger angular extent of the new six sample X-ray Source Application (XRSA)[6] cassette, a predecessor to the cassette tested at the National Ignition Facility[7], caused us to further question the assumed spatially isotropic nature of the X-ray source although no energy measurements had been made for the XRSA cassette line of sight and therefore no spatial uniformity measurements had been made either. The optical test samples were exposed to the X-ray source filtered by thin disks of Be, polyethylene (PE), and Kapton®. Pre- and post-shot measurements for each optical sample were performed.

II. X-RAY SOURCE AND SAMPLE CASSETTE

The X-rays for the OMEGA II and III tests were created from ultra-low density Ge-doped SiO_2 aerogel targets.[4] The Ge-doped aerogel material was cast in 75 μm thick Be cylinders that ranged from 1.2 to 2.2 mm in length and had inner diameters IDs from 0.9 to 2.5 mm. The cylindrical shape of the source and the resulting geometry of the laser-driven X-ray generation suggested to us that the isotopic point source assumption was questionable unless the exposed test object was far enough away from the source or was aligned directly along an axis of symmetry.

A single-sample (SDC) cassette and a six-sample XRSA cassette were loaded into the test instrument manipulator (TIM) 2 and TIM 3 at set distances and view geometry with respect to the cylindrical Ge-doped aerogel targets. The SDC cassettes were

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positioned between 100 and 120 mm away from the X-ray source center and the XRSA cassettes were positioned between 200 and 240 mm away. Each TIM line of sight was able to view the cylindrical wall (WALL) side of the Be cylinder as well as the laser entrance hole (LEH) that would theoretically produce unique energy spectra, time dependence and energy fluence. The expected spectra from the LEH direction should be less attenuated and contain more low energy X-rays than the WALL direction since there is less material in the LEH direction between laser generation and the "outside world". For more information on the XRSA cassette see reference 6.

III. ANOMALOUS OMEGA III TEST RESULTS

A test anomaly occurred during OMEGA III shot 24811 on the XRSA. The cassette was loaded with 6 samples, two sets of three identical samples. Sample positions 1 through 3 had the same protected Ag coated mirror samples behind three different X-ray filters including 25 µm Be, 25 µm PE and 25 µm Kapton. The X-ray absorption characteristics were expected to produce three different energy fluences with correspondingly decreasing magnitude although the mirror sample behind position 2, which was filtered by 25 µm PE, was more severely damaged than the sample filtered by 25 µm Be (Fig. 1). This result was outside our analytical uncertainty and contradicted our understanding of the physics. The only answer we could conclude was that our assumption concerning the isotropic nature of the energy fluence and/or energy spectra of the source was incorrect or some other unknown damage mechanism was present.

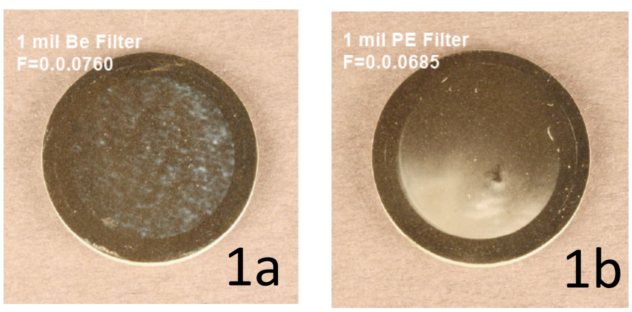

FIG. 1. a) Sample exposed behind 25 µm beryllium and b) sample exposed at "lower fluence" behind 25 µm of PE.

IV. SPATIAL ISOTROPY MEASUREMENT

The OMEGA III anomaly caused the optical component test team to have concerns about the assumption of the source and a technique was developed to qualitatively characterize the X-ray spectra across several large energy bins. [NOTE: the term qualitative is used since the films and image plate were not calibrated across the range of photon energies.]

Several approaches were attempted using two types of Radiochromic film and one type of image plate. We adapted the XRSA test cassette[6] to hold multiple X-ray filter materials followed by two radiochromic film types (FWT-60[8] and HD-810[9] Gafchromic® film); the Fuji image plate[10] (IP) was shown to be much too sensitive for the test application. The first measurements of the spatial non-uniformity were performed during OMEGA V test (26 Oct 2010) experiment yielding a large variation for the measured dose behind a 25 µm thick Be filter (this measurement corresponds to the lowest energy bin). All higher energy measurements (i.e., dose measurements behind more absorbing filters) yielded spatial non-uniformity of a few percent and were within the expected uncertainty.

The FWT-60 dosimeter is composed of hexa (hydroxyethyl) pararosaniline nitrile held in a nylon matrix. Its sensitive dose range is from 1 to 200 kGy (0.2 to 50 cal/gm). The HD-810 consists of a gelatin surface layer, an active polymer of diacetylene in gelatin, and a clear polyester substrate. Its dose range is linear between 0 and 250 Gy (.05 cal/gm). The image plate (IP) was much too sensitive for these measurements and saturated even with maximum filtering in place. NOTE: The IP was therefore too sensitive for this specific application but will be re-considered for more sensitive applications.

V. MEASURED DATA

The measured radiation dose for each RC film can be related to optical density (OD) at specific wavelengths: 510 and 600 nm for FWT-60 and 615 and 680 nm for the HD810 film. We used an Ocean Optics USB2000+ Fiber Optic Spectrometer to measure the OD of these films and compared these measurements for each of the filter conditions. The change in OD between the exposed and the unexposed samples are then related to the dose using the ΔOD to dose response data. Example FWT-60 RC film data taken during Shot 3 from the OMEGA V test (26 Oct 2010) are given in Fig. 2 and the corresponding spectral transmission measurements are shown in Fig. 3. The measured dose as a function of position for FWT-60 RC film around the XRSA cassette is given in Fig. 4.

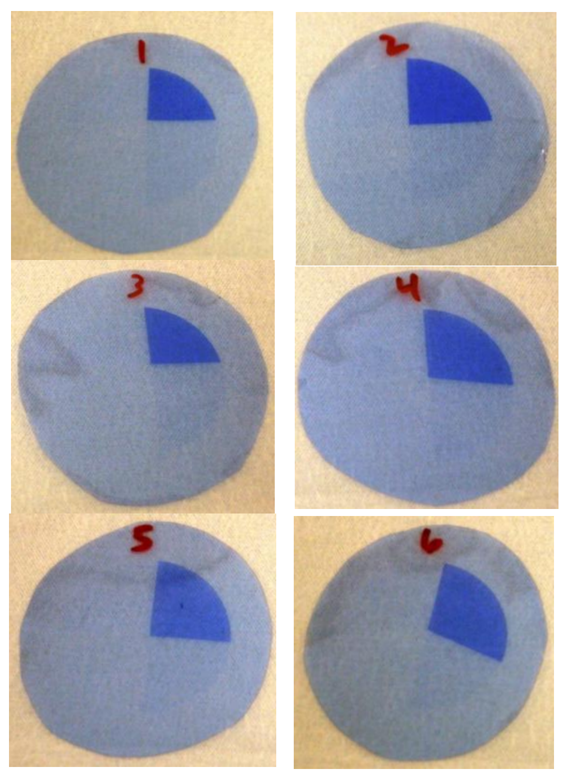

FIG. 2. Exposed FWT-60 optical transmission film photographs for positions 1 through 6 in the XRSA cassette.

The second layer RC film (HD810) was a much more sensitive dose measurement, as shown by the vivid and contrasting images in Fig. 5. The images and corresponding dose measurement provided no evidence of spatial non-uniformity, as expected, since only higher-energy X rays penetrated the first FWT-60 RC film.

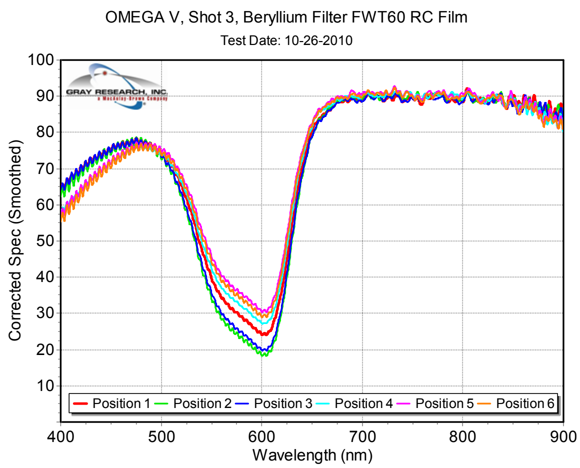

FIG. 3. Post-Exposure FWT-60 optical transmission film for positions 1 through 6 behind 25 μm Be filter.

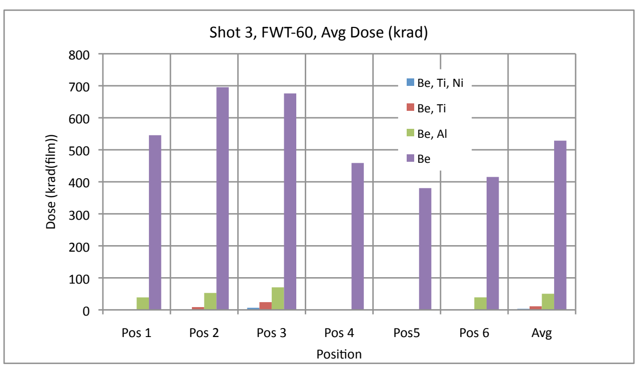

FIG. 4. Measured dose as a function of XRSA cassette position as X-ray filter combination.

The measured and corresponding fractional standard deviation of the first layer RC film (FTW-60) was large for the Be filtered cases; greater that 25%. The change in optical density for the other filtered cases was much more difficult to measure and inconclusive. For comparison, the measured dose in the second layer of RC film (HD-810) was much more contrasting and consistent in comparison with the pre-shot optical density with a fractional standard deviation of 10% or less. We conclude that these semi-quantitative measurements provide evidence of spatial non-uniformities for the lower energy photon energies, E < 3 KeV. Analysis and further experimentation is justified to better understand this anomaly.

VI. SIMULATION ANALYSIS

A limited set of X-ray transport calculations were performed to better understand the energy dependence of the transmitted spectra through each of the specific filters as well as to understand the deposited energy into the RC film. These calculation verified that the 25 μm Be filter case allowed for photons with energies greater than 1 keV to penetrate and be deposited into the first layer RC film. The transported energy spectra for the other cases were attenuated by many orders of magnitude for energy less than 5 keV. These calculations should be expanded and correlated with quantitative RC film measurements. Therefore, we recommend further research to calibrate the RC film and IP materials so a more quantitative measurement can be performed.

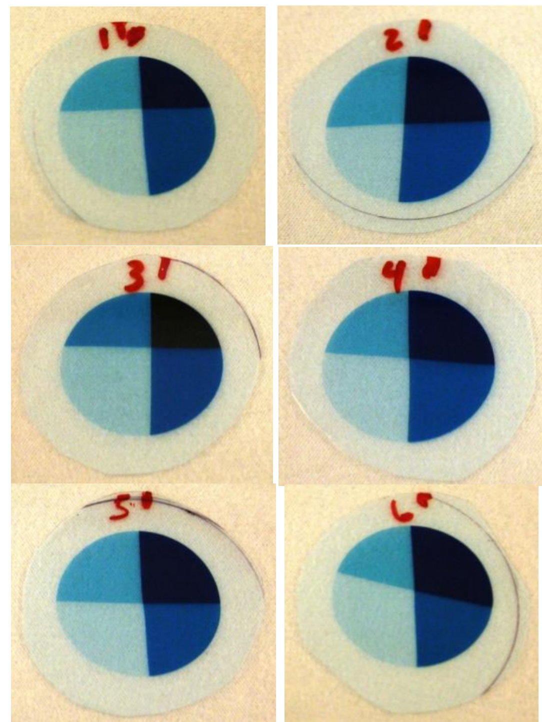

FIG. 5. Exposed HF-810 optical transmission film photographs for positions 1 through 6 in the XRSA cassette.

VII. CONCLUSIONS

A qualitative technique was developed to provide information about the uniformity of laser induced X-ray sources that is compatible with X-ray facility instrumentation interfaces at facilities like OMEGA and NIF. The technique provides spatially dependent dose and/or energy fluence uniformity measurements over the sample exposure area and the existing XRSA cassette could be modified to better or specifically characterize the X-ray source. We encourage more research including calibration of the RC films and IP material, simulation analyses to evaluate with the X-ray transport and energy deposition, and further experimental validation.

[1]O.L. Landen, *et al.*, Rev. Sci. Instrum. **72**, 627 (2001).
[2]B.E. Blue, *et al.*, Phys. Rev. Lett. **94**, 095005 (2005).
[3]K. Fournier, *et al.*, Phys. Plasmas **17**, 082701 (2010).
[4]K. B. Fournier, *et al.*, Phys. Plasmas **16**, 052703 (2009).
[5]K. B. Fournier, *et al.*, J Rad. Effects Research and Engineering **28**, 33 (2010).
[6]K. Fournier, *et al.*, Rev. Sci. Instruments (this conference).
[7]K. B. Fournier, *et al.*, Rev. Sci. Instrum. **81**, 075113 (2010).
[8]http://www.fwt.com/racm/fwt60ds.htm
[9]A. Niroomand, *et al.*, Medical Physics **25**, 2093-2115, (1998).
[10] A. L. Meadowcroft, *et al.*, Rev. Sci. Instrum. **79**, 113102 (2008).